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Design and test of a custom instrumented leg press for injury and recovery intervention

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Abstract

There is an increasing desire and emphasis to integrate assessment tools into the everyday training environment of athletes. These tools are intended to fine-tune athlete development, enhance performance and aid in the development of individualised programmes for athletes. The areas of workload monitoring, skill development and injury assessment are expected to benefit from such tools. This paper describes the development of an instrumented leg press and its application to testing leg dominance with a cohort of athletes. The developed instrumented leg press is a 45° reclining sled-type leg press with dual force plates, a displacement sensor and a CCD camera. A custom software client was developed using C#. The software client enabled near-real-time display of forces beneath each limb together with displacement of the quad track roller system and video feedback of the exercise. In recording mode, the collection of athlete particulars is prompted at the start of the exercise, and pre-set thresholds are used subsequently to separate the data into epochs from each exercise repetition. The leg press was evaluated in a controlled study of a cohort of physically active adults who performed a series of leg press exercises. The leg press exercises were undertaken at a set cadence with nominal applied loads of 50%, 100% and 150% of body weight without feedback. A significant asymmetry in loading of the limbs was observed in healthy adults during both the eccentric and concentric phases of the leg press exercise ($P < .05$). Mean forces were significantly higher beneath the non-dominant limb (4–10%) and during the concentric phase of the muscle action

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(5%). Given that symmetrical loading is often emphasized during strength training and remains a common goal in sports rehabilitation, these findings highlight the clinical potential for this instrumented leg press system to monitor symmetry in lower-limb loading during progressive strength training and sports rehabilitation protocols.

Keywords: Instrumentation, feedback, leg press;

1. Introduction

This paper reports a developed and tested an instrumented leg press. Our aims were to assess the usefulness of the technology through a controlled study. The study chosen was to determine whether lower-limb symmetry is observable in healthy able-bodied subjects during the performance of an inclined leg press exercise and secondly to investigate whether feedback assists learning during this type of exercise.

Asymmetry in lower-limb loading during bipedal movement tasks is common following musculoskeletal injury and joint replacement surgery (Boonstra (2008), Christiansen et al. (2011), Turkot et al. (2012)). Although return to symmetrical loading remains a common goal in sports rehabilitation (Barber-Westin & Noyes (2011)), and measures of asymmetry have been used to monitor rehabilitation strategies (Mizner et al. (2005), Talis et al. (2008)), the determinants and extent of loading asymmetry in many strength and conditioning exercises of the lower limb have not been described fully.

The acquisition of particular skills in sport extends to injury recovery and performance enhancement and thus is important to the elite and developmental athlete. Skills are acquired generally through both explicit and implicit processes (see Farrow (2007). Exercise adherence and development of lifting are skills that can be assessed and learned through feedback. In general, skill is acquired when there is some knowledge of the results of an action. Augmented representations of a kinetic or kinematic movement can contribute to this knowledge and form part of the athlete's ability to detect and correct errors as part of the learning process reports Swinnen (1996).

2. Experimental

2.1. Instrumentation

The design of the instrumented leg press compromised several components to integrate several sensors together with a data acquisition module and user feedback interface (GUI). Fig. 1 shows the instrumented leg press setup. An industry-standard 45° inclined quad track sled-type leg press plate (Fitcore) was retrofitted with two uniaxial force plates (Vernier FP-BTA, Vernier Software and Technology, USA) attached to the foot plate. Each force plate had a selectable force range (full scale), and –200 to +850 N was selected to measure the applied forces beneath each leg independently. Force plates were calibrated independently using a handheld force gauge (microFET2, Hogan Scientific, Salt Lake City, UT, USA) using graduated applied force and found to be within the specification and experimental errors. Displacement of the footplate system was measured using a commercially available MULTICOMP SP1-50 draw–wire displacement transducer displacement sensor (*Resistive*) rated to 500k cycles.

A previously developed sensor interface, as reported by Davey et al. (2008), comprising an Atmel ATmega324P microcontroller was used to convert the analogue force signals to digital, giving a resolution of 1.2 N for the force plates and 1.2 mm for the displacement sensor. An interrupt-driven real-time scheduler was configured to take 25 samples per second from each of the three ADC channels, which were then transmitted to a virtual serial port USB interface to the host computer and developed GUI.

A customized client, comprising near-real-time data acquisition and display, data storage and retrieval from the hardware and a USB camera (25 Hz), was developed using Microsoft C# using Visual Studio and the .NET 4.0 framework. The developed software allowed the storage of individual athlete details (such as name and anthropometric values), sensor data and video, which were separated into epochs of individual lifts (exercise repetitions) using an adjustable threshold on the displacement sensor. Immediately after the lift, feedback of sensor data and video were provided to the athlete and was also used for post analysis of collected sensor data. All video and sensor data was stored for further analysis. A sample screen shot of the user interface is shown in Fig. 2.

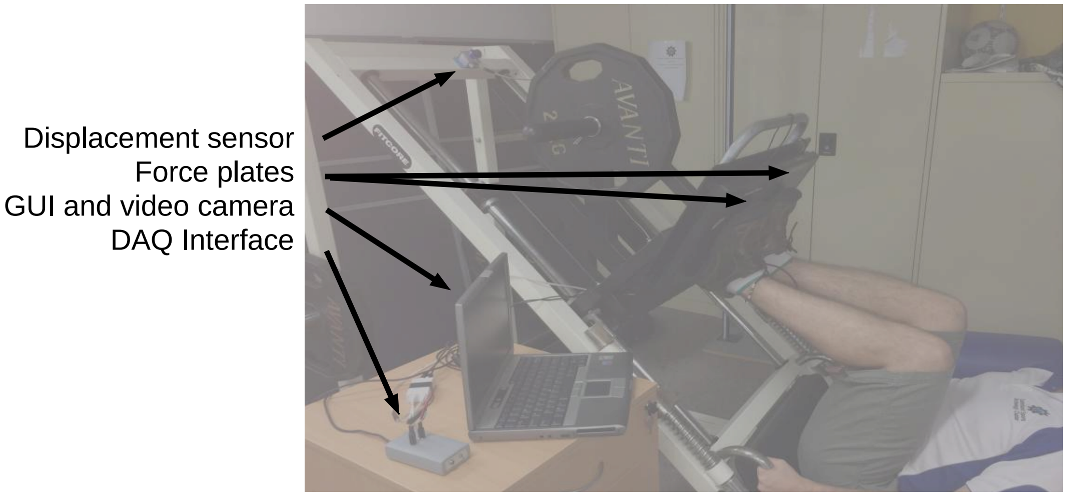

Fig. 1. Instrumented leg press concept showing key components

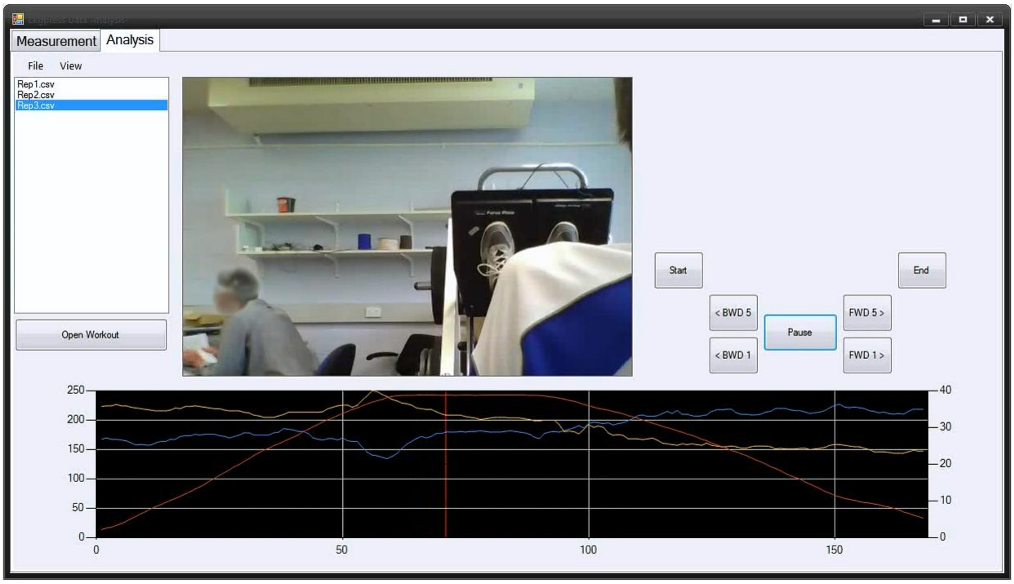

Fig 2. Instrumented leg press graphical user interface (GUI) showing tabbed operation modes Measurement and Analysis. Video replay features are in the centre with sensor data display below. The sensor data comprised left (yellow) and right (blue) force, together with displacement (red) over time. The video camera angle is flexible as needed in the experiment.

2.2. Methods

Eight recreationally active adults (five men, three women) completed a series of leg press exercises using the instrumented 45° sled-type leg press. Participants were non-smokers, did not take medication and were recreationally active based on self-report. No participant reported a history of diabetes, inflammatory joint disease, familial hypercholesterolaemia or lower-limb pathology that could inhibit his or her performance of the exercise protocol. All participants gave written informed consent before participation. The study received approval from the university human research ethics committee and was undertaken according to the principles outlined in the Declaration of Helsinki.

Participants reported to the laboratory wearing lightweight, comfortable clothing and having abstained from vigorous physical activity in the previous 24h. Body height (stretch stature) was measured to the nearest millimetre using a Harpenden stadiometer (Cranlea and Co., Birmingham, UK), and body weight was recorded to the nearest gram with clinical scales (Tanita, Tokyo, Japan). Body mass index (BMI) was estimated by dividing body weight (kg) by the square of body height (m^2). Before the leg press exercise, lower-limb preference and laterality were assessed using previously defined methods (see Dodrill & Thoreson (1993)). In brief, the mobilizing limb during kicking was defined as the dominant limb, and the stabilizing leg during kicking was defined as the non-dominant limb using Sadeghi et al. (2000).

Leg press exercises were then undertaken at nominal applied loads of 50%, 100% and 150% of body weight at a 1–0–1–1 cadence of three counts at 54 beats per minute. Cadence was set as a single-count eccentric motion during which the hip and knee joints moved from extension to 90° of flexion, and this motion was followed immediately by a single-count concentric motion to full extension, with a single-count rest and recovery beat before beginning the next repetition as set out by Hanson et al. (2007). A minimum of nine repetitions were completed at each weight category as outlined by Paulus & Schilling (2009), and the force beneath each foot and displacement of the foot platform were recorded synchronously at 25 Hz.

The Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) was used for all statistical procedures. The Kolmogorov–Smirnov test was used to evaluate data for underlying assumptions of normality. Outcome variables were determined to be normally distributed, and mean and standard deviation are used as summary statistics. Statistical comparisons between the mean force beneath the dominant and non-dominant limbs during eccentric and concentric phases of loading were made using two-way repeated-measures ANOVA within a generalized linear modelling framework. An alpha level of .05 was used for all two-tailed tests of significance.

3. Results

The mean age, height, mass and BMI of participants were 32 ± 9 years, 1.77 ± 0.14 m; 75 ± 16 kg and 24 ±3 $kg.m^{-2}$, respectively. The right leg was the dominant limb during kicking in all but one participant.

Average force beneath the dominant and non-dominant limbs for each loading condition of the leg press exercise are summarised in Figure 3. There was a significant main effect for limb and muscle contraction for each loading condition ($P<.05$), indicating asymmetrical loading of the limbs during both eccentric and concentric phases of the leg press. Mean forces were significantly higher beneath the non-dominant limb (4–12%) and during concentric muscle action (5%).

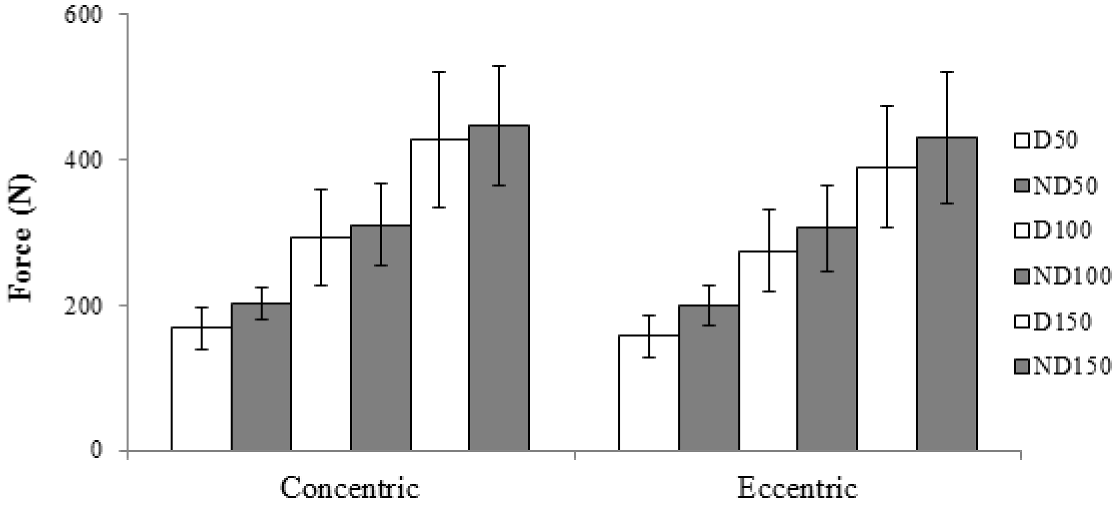

Fig 3. Mean force beneath dominant (D) and non-dominant (ND) limbs during a bipedal 45° inclined leg press with nominal applied loads of 50%, 100% and 150% of body weight. Results are reported L to R D50, ND50, D100, ND100, D150, ND150 for both concentric and eccentric lifts.

4. Discussion.

This study developed an instrumented leg press to evaluate the symmetry of loading between limbs in healthy adults and was found to be a useful tool for quantifying leg press action. In the study phase it was found there was relatively greater loading of the non-dominant limb during the leg press exercise. This asymmetry was more obvious during the eccentric compared with the concentric movement phase of the exercise. These findings differ from previous observations by Flanagan & Harrison (2007) in which force symmetry was observed in young adults during jumping on an instrumented sled. The findings also differ from those of a previous study of a bipedal sit-to-stand (concentric only) movement, in which marked asymmetry in load was observed in healthy adults but was unrelated to limb dominance (Hesse et al. (1996)). The results of this study suggest that normative baseline values should be used cautiously for planning therapy and highlight the potential of an instrumented leg press for monitoring asymmetry in lower-limb loading during progressive sports rehabilitation.

Although discrepancies between eccentric and concentric leg strength have long been implicated in sports injury such as MacLean et al. (1999) and Sugiura et al. (2008), the differences observed in total force between concentric and eccentric movements in the current study likely reflect inertial effects and friction of the quad track roller system of the leg press machine. Further investigation is required to confirm this.

The use of an instrumented leg press to monitor loading symmetry has some limitations. Although performance in leg press exercises has been shown e.g. Foldvari et al. (2000), to be a strong predictor of self-reported functional status in elderly women the level of asymmetry observed during leg press exercises in this small cohort of healthy adults may not apply directly to other cohorts or activities of daily living, such as stair ascent or walking. Similarly, although the technology may provide clinically meaningful loading information, the prototype outlined in this paper requires expert use and may be cost prohibitive in its current form.

Finally, although in the main study, we deliberately avoided providing participants with feedback about load symmetry between limbs throughout the exercise task, the system is capable of providing near-real-time feedback and is ideally suited to a faded-feedback approach. Crowell & Davis (2011) have found this has been successful in retraining lower-extremity loading patterns during running. A second study allowed visual feedback of lifting dynamics (displacement and force time curves) to be provided to the athlete in near real-time. In all cases, lifting symmetry and motion during both eccentric and concentric activity were disrupted. This suggests that motor learning was underway and that a more thorough investigation is required to control and monitor such learning better. Further research is needed to evaluate the efficacy and effectiveness of biofeedback in promoting sustained loading symmetry during rehabilitation and progressive strength training.

5. Conclusions

A video feedback, force and displacement instrumented leg press was developed and applied to a lifting study to demonstrate its utility. The study found there was relatively greater loading of the non-dominant limb during the leg press exercise. This asymmetry was more obvious during the eccentric compared with the concentric movement phase. These findings show that this instrumented leg press may be useful for monitoring symmetry in lower-limb loading during progressive strength training and sports rehabilitation. Video feedback to the athlete was also investigated and will be the subject of further investigations. The technology shows great potential for rehabilitation and skill acquisition in athletes for the future.

Acknowledgements

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